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I.   INTRODUCTION

In our previous working paper (#1284-82) we concluded that one of the chief contributors to productivity decline is poor strategic management. For example, we noted the inability of U.S. automobile manufacturers to make significant innovations to increase value added. Now we need to understand what are the factors of this seeming inability to make the strategic investments at the appropriate time.

To do so, we first need to understand the effects of technological advances on supply and demand which act as positive incentives for firms. We then develop more fully our notion of critical fixities, which act as inhibitors to the investment process, examining the issue both theoretically and empirically.

We would like to begin by conceptualizing the notion of innovation in a larger framework. We define innovation as a reconfiguration of existing material which enables users to facilitate the means of achieving utility. Innovation is produced by providing a new context for existing matter. It is a unique or "new" way of putting things together. To use the terminology we have used earlier, it is the meaning generated by the context in which data is put. This context provides the beholder a competitive advantage temporarily, the extent of which depends upon the ability of others to imitate. This ability, in turn, is dependent upon the state of development of potential imitators vis-a-vis the new context. If others are at a similar or proximate state of development, the innovation will be adopted quickly, unless other barriers to imitation exist.

The implication is that the greater the ability of an organization to provide a significantly different context or reconfiguration, the greater change will be, and the more insulated it will be from competition by imitators.

What is the result or effect of this change? It is customary to consider two types of innovations - product and process, the latter referring to changes in the production process or means by which a given product is produced, and the former referring to the development of a "new" or different product. For example, in Table 1 we present William Abernathy's list of product and process innovations in the U.S. automobile industry in mass-produced cars and assembly plants.

However, while it may be enabling for purposes of discussion to dichotomize innovations in such a way, in practice it may not be so easy to do. The matter becomes particularly muddied when we consider the relationship between buyers and suppliers. What is a product innovation to the supplier often becomes the process innovation of the buyer. For instance, any new innovation can be considered to be a process innovation in that it will increase one's ability to "produce" a product or service, broadly defined. For example, a can opener (a product) becomes part of a process in "producing" a meal; an automobile becomes part of a process to "produce" a trip. In this sense all process innovations are actually product innovations and vice-versa. Therefore, it is important to keep in mind the context in which the innovation is utilized or realized in determining whether to classify an innovation as product or process.

However, in terms of profit-maximizing firms, the intended result of any innovation is either to increase revenues or reduce costs. Generally speaking, a process innovation is intended to reduce costs and a product

Table 1

THIRTY-FIVE MAJOR TECHNOLOGICAL INNOVATIONS IN MASS-PRODUCED CARS AND ASSEMBLY PLANTS

Decade	Product Innovation	Process Innovation
1900-1909	Lightweight durable chassis (Model T)	Interchangeable parts and progressive manufacturing in automobiles (Cadillac) Overhead conveyor for parts
1910-19	Electric starter Electric lights	Moving final assembly line
1920-29	Closed steel body Hydraulic and four-wheel brakes Lacquer finishes (DUCO-pyroxylin)	Welding in body and chassis assembly Growing use of light, powered hand tools
1930-39	Independent suspension Power brakes All-Steel body, turret top, and streamlining	Unit body construction High-frequency portable power tools Multihydromatic welding
1946-54	Automatic transmission Power steering Air conditioning	Multiple nut runners automatic spray painting Electrostatic painting Electronic-assisted scheduling Higher-speed and automated stamping
1955-64	Disc brakes Improved suspension systems Alternator	Body-corrosion protection Expanded use of special-purpose fasteners Mixing of body styles on assembly lines
1965-74	Energy-absorbing steering wheel and column Energy-absorbing bumpers and front ends Electronic sensors of car mechanisms	Automated chassis and body assembly Powder coatings (paint or body)

SOURCE: William Abernathy, 1978, p. 53.

innovation is intended to increase revenues - one deals with supply and the other with demand. The net result, however, is increased profitability (again, intendedly) and this provides the incentive for the firm to innovate.However, in order for an incentive to be effective, it must be recognized or perceived. How can a decision-maker determine if innovation exists and what its effects might be?
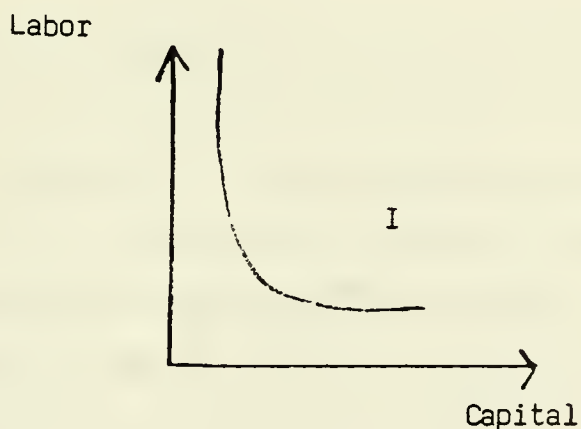
II.   MEASURES OF TECHNOLOGICAL CHANGE

Sahal (1980) discusses three means that have been used to measure technological change: the production function, patent statistics, and functional properties of a product. We would like to discuss each of these to determine their utility for our analysis.

A.   The Production Function

As related previously, a production function expresses the relationship between the various technically feasible combinations of input(s) for producing a given level of output. It is often expressed in terms of a set of convex isoquants, as for example,

Labor

I

Capital

The curve I shows all feasible combinations of labor and capital that will produce a certain output.

Now the argument is that a change in the production function reflects technological change, i.e. a new set of technically feasible combinations will

come into existence due to some change. For example, technological change would cause the above isoquant curve to shift, such as
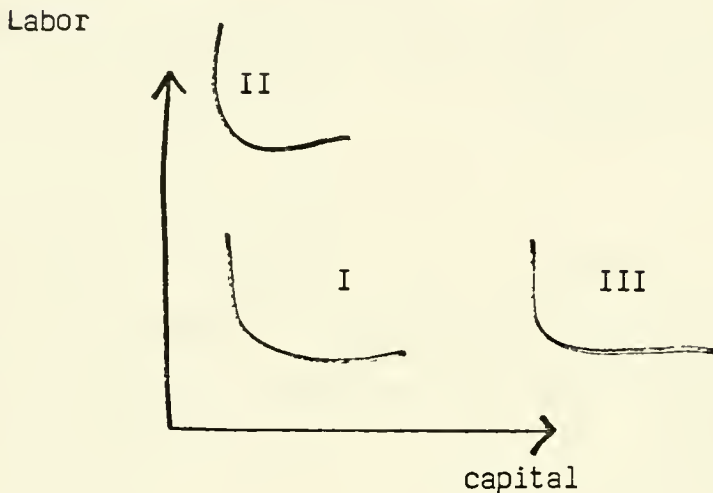

In the figure above, the change from isoquant II to isoquant I would represent a technological advance that is labor-saving and the change from III to I, one that is capital-saving, i.e. it requires less of that particular input (and the same amount of the other) to produce the same amount of output.

Unfortunately, the production function is not observable directly, but we can observe the factor input ratio and factor prices, which may then tell us if change has occurred. However, assuming only two inputs, capital and labor, there is, in fact, more than one reason that a capital-labor ratio might change. For example, it may be due to i) a change in output level; ii) a change in factor prices and/or; iii) a change in factor values.

When output levels change, of course, the amount of each input will also usually change, but the difference in the input ratio will depend on the expansion path dictated by the technology. For example, two kinds of expansion paths are shown below. Path I represents expansion with a decrease

in the capital-labor ratio and Path II, with an increase. Thus, a change in output may cause a decrease or an increase in the capital-labor ratio.
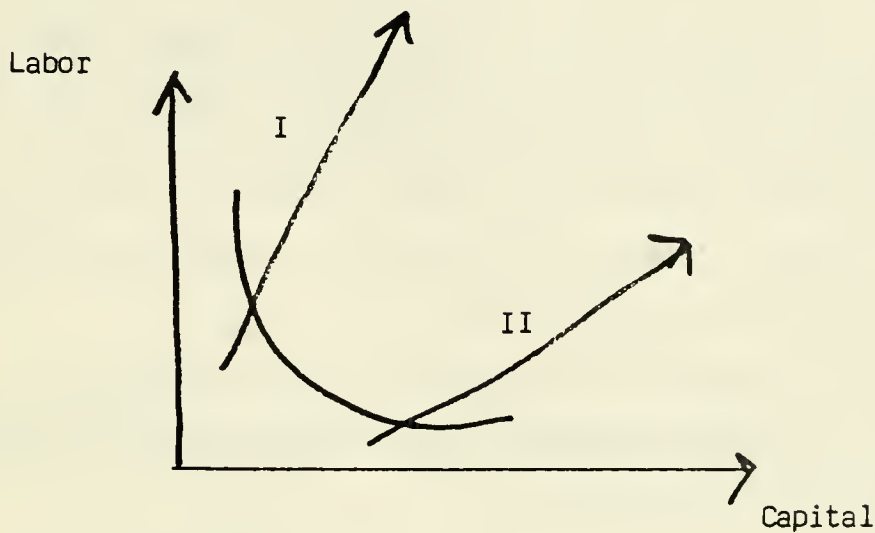
Now let us look at the other two possibilities - a change in input prices or input values.

According to economic theory, every input should be employed at the level where its marginal revenue product (MRP) is equal to its marginal cost, i.e. these two factors determine the level of inputs that will be employed by a firm and, hence, determine the input factor ratio. This implies that a change in the levels will be caused by a change in either one of these factors. The change itself can take two forms, assuming only two factor inputs - either a one-for-one substitution between inputs or an absolute reduction in input levels. Let us take the latter case first. A process innovation will usually alter the MRP of a factor input, which means that it enables the input to produce more output for the same level of input or, put another way, it takes less input to produce the same level of output. For example, if an old technology requires two "units" of machines and ten units of labor to produce ten units of output, then a labor-saving process

innovation would be one in which only five units of labor and two of machines are required to produce the same output.

In the case of a change in factor prices, we would expect to see a substitution of the less expensive factor for the one whose price is rising. In this case, the change in the factor input ratio would not reflect an innovation (unless the price rise was due to such). However, the extent to which one input is replaced by the other is a function of the substitutability, and here, process innovation may play a role.

Substitutability is measured by the extent to which the changes in relative factor prices affect the relative levels of inputs. That is, the elasticity of substitution, σ, is given by:

$$\sigma = \frac{d(\frac{K}{L})}{\frac{K}{L}} \cdot \frac{\frac{w}{r}}{d(\frac{w}{r})} \tag{1}$$

where K is capital, L is labor, w is wages, and r is the cost of capital. A numerical example will show how this operates. Assume that the indeces of w,r,K, and L are initially set at 100 and therefore, both the capital-labor, ratio, K/L, and the factor price ratio, w/r, are equal to one. If wages increase by 10%, and the cost of capital remains unchanged, then the factor price ratio, will increase by 10% to 1.10. Under these circumstances the firm will tend to substitute capital for labor, so that the capital-labor ratio would also increase. If $\sigma = 1$, equation (1) tell us the firm will be able to increase the capital-labor ratio by 10% to 1.1. As a result, the ratio of total wages (wL) to total capital costs (rK) will not change, to wit,

$$\frac{rK}{wL} = \frac{r}{w} \cdot \frac{K}{L} = \frac{1}{1.1} \times 1.1 = 1$$

By the same token it can be shown that if wages increase and $\sigma < 1$, then this ratio will decrease. The importance, then of this elasticity, should be evident.

These results are very relevent to our productivity measure, value-added over payroll and benefits where, value added is the sum of total capital costs, labor costs and operating profits. Ignoring profit for the time being, we have

$$VA = wL + rK \tag{2}$$

Dividing (2) by wL, we derive our productivity measure:

$$\frac{VA}{wL} = 1 + \frac{rK}{wL} \tag{3}$$

Thus, if $\frac{rK}{wL}$ decreases, productivity will show a decrease. Therefore if wages increase and $\sigma < 1$, the ratio rk/wL will decrease and our productivity measure will show a decrease. On the other hand, if wages increase and $\sigma = 1$, our productivity measure will not change, because the increase in wages can be totally offset by substituting capital for labor. The same sort of reasoning can be applied to a situation where $\sigma > 1$.

In the previous paper (#1284-82), we suggested that one of the reasons for the decline of productivity was that wage rates grew faster than the growth of physical labor productivity. Now we can see that this alone is not a sufficient condition for the decline, but rather a sufficient condition would require the elasticity of substitution to be less than one, so that the increase in wages could not be completely offset by an increase in capital. These two factors then help to explain productivity decline, and as we have pointed out, process innovation may be a significant factor in determining the elasticity of substitution.

This discussion shows us some of the benefits from innovation, but it also demonstrates that the production function is a difficult approach to use in measuring innovation and its effects. However, at least we can state that where it _is_ useful, it will be so in measuring process innovations rather than product innovations. This is because process innovations, by definition, affect inputs, given output levels of the existing production process, and thus, their effects are reflected in a change in the production function for a given product. Other measures would be more suitable to measure these types of innovations.

B.   The Functional Property Approach

As indicated, the distinction between product innovation and process innovation rests with the user of the innovation. The same innovaton can be a process innovation for a user and product innovation for the supplier. From the user's point of view, we have used the production function concept to describe the economic effects of process innovations. To measure product innovations, some have used another instrument, known as the functional properties approach.

This approach is fairly straightforward in that it argues technological change should be described or measured in terms of properties, such as the thermal efficiency of a power plant, or the capacity of a blast furnace. This approach, called by Sahal the system's view of technology, has been widely used in the engineering literature.

However, while this is certainly a valid methodology it would be more useful to managerial decision-making if it were related more to ecnomic varaiables such as prices or demand. But we can make such a linkage, albeit somewhat crudely. For example, consider the case where advances in computer technology increase calculation speed by orders of magnitude. Suppose that

this is the only functional property that creates consumers' utility. Then, the prices of different computers with varying calculation speeds can be standardized by this characteristic. If a new computer (with price equal to the old one) is ten times faster than an old one, it is viewed as ten old ones and its real price is one-tenth of its listed price. This real price may be called the "functional equivalent price." Since the functional equivalent price is less than the price of the old one, substitution in the demand function will take place. However, in reality, a product innovation has more than one functional property and the estimation of the "functional equivalent price" is almost impossible. But the substitution effect represents a drop in the real price of a product, and thus it stimulates demand.

Probably more importantly though, product innovation can also have promotional effects as well, in the sense of creating and satisfying new needs. Promotional effects of a new technology can be observed either in its increasing the growth of a specific new industry, e.g. nuclear weapon manufacturing, or in its encroaching on the growth of other competing industries, e.g. gasoline engine automibles vehicles substituting for steam engine automobiles. However, whether effects are substitutional or promotional, functional properties are often difficult to quantify and thus make determination of economic returns even more difficult, which is more than problematical to decision-makers.

C.   The Patent Statistics Approach

Another measure can be used to measure both process and product innovations. A number of economists have used patent statistics as a measure of technological advancement, such as the number of patents issued (e.g. Scherer, 1965). Most of the research done has attempted to test Schumpeter's hypothesis that there are increasing returns in R&D both to the size of the

R&D establishment and to firm size, by using the number of patents issued to a firm as an output measure and the size of R&D and firm as input measures. The basic assumption underlying the use of this measure is that the number of patents accurately captures the number and degree of technological innovations. However, in our opinion, patent statistics suffer from several drawbacks as indicators of innovations.

First, patent statistics fail to reflect the varying importance of different innovations. The existence of a patent gives no assurance of the intellectual meaningfulness or commercial value of an innovation. Second, some useful innovations are not patentable and thus patent statistics excludes them. Third, patent statistics may be an inverse function of technological advancement, because the vastness of technological opportunities is a disincentive for patent applications. Let us elaborate this last point.

The basic economic motivation to apply for a patent is to secure monopoly rent. However, patent application rules require full disclosure of the features of the innovation, which obviously facilitates competitors in imitating the innovation. Therefore, innovators will evaluate the tradeoff between the potential gain of monopoly power and the probability of being quickly imitated. We hypothesize that innovators will favor patent applications when the industry's technology and/or products become mature.

In mature industries the degree of product differentation is ususally small and thus the market is generally competitive. Arrow (1962) has shown that the incentive to gain monopoly rent (by having a patent) is greater for firms in a competitive market than for firms in an innovative industry which have some monopoly power, because of their technological supremacy. As well, because technology is changing so quickly, one is more concerned with obsolescence than holding on to one's technology.

However, as an industry becomes mature, the chance of being bypassed because of technological leaps will decline, and thus the incentive for patent applications should increase. Therefore, we hypothesize that the number of patents will be higher in a stagnant industry than in an innovative industry.

In sum, the above three arguments put into question the use of patent statistics as a measure of technological advancement.

III. OVERVIEW

We now have discussed three different approaches that are used to measure technological changes--production function, patents, and functional properties. We have concluded that the production function would be more appropriate in measuring process innovations, functional properties in measuring product innovations, and patents as not particularly useful at all. However, none are as robust as we would like, at least in terms of providing enabling instruments to decision-makers.

It may be that it would be more helpful to consider the issue of innovation in the context in which the decision-maker views it--as a resource allocation decision. One such investment model has been developed by Zannetos (1966) and extended by Papageorgiou (1981). We present this model below.

A positive sign for the sum of the appropriate equations over n years of operations means that the investment is viable, whereas a negative sign means that the investment is unacceptable.

A.   If $R_i - V_i - I_I - D_i - L_{i-1} > 0$

then the investment equation for year i has the form

$$- E_i G_i + [(R_i - V_i)(1 - t)] G_i - P_i J_i +$$
$$[I_i + D_i + L_{i-1}] t H_i \tag{1}$$

If $R_i - V_i - I_I - D_i - L_{i-1} \leq 0$

then the investment equation for year i has the form

$$- E_i G_i - [(R_i - V_i)] G_i - P_i J_i \tag{2}$$

C.   For the last year, n, of operations:

If $R_n - V_n - I_n - D_n - L_{n-1} + S_n + K - \sum_{j=1}^{n} D_j > 0$

then Equation (1) becomes

$$-E_n G_n + [(R_n + S_n - V_n)(1-t)] G_n - P_n J_n +$$

$$[I_n + D_n - L_{n-1} + K - \sum_{j=1}^{n} D_j] \, t_G \, H_n \tag{3}$$

D. For the last year, n, of operations:

If $R_n - V_n - I_n - D_n - L_{n-1} + S_n + K - \sum_{j=1}^{n} D_j \leq 0$

then Equation (2) becomes

$$- E_n \, G_n + [(R_n + S_n - V_n)] \, G_n - P_n \, J_n \tag{4}$$

where

R_i = Revenue for year i

C_i = Capacity, adjusted for average unemployment, for year i

V_i = Variable costs for year i

P_i = Debt related payment for year i

I_i = Interest payment for year i

D_i = Depreciation for year i

L_i = Accounting Loss for year i

$\quad = R_i - V_i - I_i - D_i - L_{i-1}$, if $R_i - V_i - I_i - D_i - L_{i-1} < 0$

$\quad = 0 \qquad\qquad$, if $R_i - V_i - I_i - D_i - L_{i-1} > 0$

S_n = Salvage value

K = Historical Cost of asset

E_i = Equity infusion for year i

G_i = Operating cash flow discount factor for year i

H_i = Tax shield discount factor for year i

J_i = Debt-related payment discount factor for year i

t = Income tax rate

t_G = Capital gains tax rate

(Note $L_0 = 0$)

Comparative statics analysis directly follows from this model. For example, the evaluation of a process innovation which leaves revenues the same but lowers costs can be easily done. Assuming that Equation (1) holds and using that primed variables to denote an old technology, we have for year i:

$$- (E_i - E_i') G_i + [(V_i - V_i') (1-t)] G_i - (P_i - P_i') J_i$$
$$+ [(I_i + D_i) + L_{i-1} - I_i' - D_i' - L_{i-1}'] t H_i$$

Summing over 4 years, and adjusting for probable exhaustion of the old capital stock by taking into account the switching cost of a completely new capital stock, through E, we can calculate the advantage of a process innovation.

Similarly, we can assume that a product innovation will leave variable costs the same, but increase revenues, in which case we have for year i:

$$- (E_i - E_i') + [(R_i - R_i') (1-t)] G_i - (P_i - P_i') J_i$$
$$+ [(I_i + D_i + L_{i-1} - I_i' - D_i' - L_{i-1}'] t H_i$$

This model brings to the decision-maker a framework to consider the critical variables in the investment process. These, of course, are not all unknown to managers. When one sees the condition of industries such as automobile manufacturing, one is forced to ask if these variables were indeed considered, and if so, why weren't the 'rational' decisions made? To answer this we present in the next section the notion of critical fixities as major inhibitors of strategic change.

IV. CRITICAL FIXITIES

We would now like to explain in more detail the concept of critical fixities as inhibitors of innovation and productivity. To do so we refer back to our theoretical model of the firm developed in Chapter 5. There we saw the firm presented in a systems framework, as a mechanism transforming inputs into outputs, which then became feedback into the entire process. This view conceptualizes the firm as a mechanism that seeks a steady state, such as the homeostat described by Ashby (1963). However, the mechanism must constantly adapt to changes in the environment, as the thermostat adjusts to changes in room temperature, for example. Yet we have observed that firm behavior is not so automatic or predictable, but rather often exhibits inertia in response to changing conditions. Why might this occur? A logical place to start in answering this, would be to look at the stages of the response mechanism, and we can use our example of the thermostat to illustrate. The thermostat monitors a specific dimension of the environment - temperature - and has a setting which is meant to be the level of equilibrium. When the critical dimension reaches a point below this standard, then a response is triggered. This triggering mechanism activates the heating unit, which then release heat into the environment to bring the temperature back into equilibrium. Thus, we can see several critical dimensions which affect response, such as monitoring, setting, and releasing.

The first problem may be that there is not a proper monitoring of the environment. There may be no scanning at all or it could exist but might not be adequate for several reasons. One is that it is not broad enough, it has not encomposed a sufficient field as to actually cover what the environment is. Another is that the firm is not monitoring the right dimensions.

The second problem is somewhat related to this last point, that is that the standard, the setting, is not set properly. Action is initiated too late, in the sense that the situation requires a massive response, whereas if the alarm was sounded sooner, a minor adjustment may have been all that was needed.

The third problem lies in the relay of the problem to another unit that must operationally attack the problem. In this situation, the environment was monitored and the problem detected, but the response is not forthcoming--again, for several potential reasons. One possibility is that the communication link is poor or the unit cannot understand the meaning of the relay, i.e. it doesn't know what it means and, hence, how to respond. Another is that it does know how to respond, but is unable to do so effectively, either because it does not have the capacity or it is not efficient, and thus responds slowly.

In actuality, of course, a problem could be a combination of any of the above, and, if we again come back to the U.S. auto industry, we can surmise that it appears as if this was indeed the case. We have shown that our productivity measure indicates an unambiguous and consistent decline since around 1962 for both GM and Ford, and that their response to this was late and slow. One could argue, as some have, that the U.S. firms saw the imports making some inroads but did not take the threat seriously. Others have argued that the bureaucracy of the organizations made it difficult to respond, once they did see the need.

But in whatever stage these phenomena occur, we term this a "fixity", meaning an inertia that keeps an organization from responding, from adapting, from innovating, and we call its dimensions "critical fixities", in the sense that they are critical to the decisions of the firm and ultimately to its survival. The dimensions may be numerous, but we examine here perhaps the

ones related to the major factor inputs, which we call capital fixities, labor fixities, and managerial fixities. We now examine each in detail, discussing the concepts and suggesting potential measurements, building as we go along a theoretical model which incorporates these concepts into the decison-making apparatus of the firm.

A.   Capital Fixities

Capital fixities refer to inertia that is connected with the physical capital owned and used by a firm, that manifests itself in the inability or unwillingness of a firm to invest in new plant and equipment for product or process innovations. This is not a new concept, but it is important to recognize this issue as well as delineate all its dimensions in order to understand how it impacts resource allocation decisions.

From a purely economic point of view a firm will not invest in a new technology unless its full average cost, which include switching costs, is less than the marginal cost of the old, ceteris paribus. This implies that the lower the marginal costs, the greater will be the critical fixity for that capital. Similarly, the higher the switching costs, the greater the fixity, at any point in time.

Consider for illustration a market with the following characteristics:

1.   Product competition.

2.   Indivisible plants which cannot be easily adapted to manufacturing methods other than the most advanced techniques at the time of their design.

3.   Labor and managerial efficiency equal in all plants.

4.   Technological changes are of a labor-saving as opposed to capital-saving nature.

5.   Plants with negligible scrap value.

6.   No delay in entry and exit.

Assume now that plants built in period t embody the most advanced techniques at the time. Since we assume that technological progress will be labor-saving, the labor units required per unit of output represent the state of technology. Let L_t be the labor units required per unit of output using technology of period t. As technologies progress, labor-saving occurs such that, $L_t < L_{t-1} < L_{t-2}$.

Firms within a given industry are normally composed of plants built at various points in time. The reason that outmoded plants exist is that these plants will not be scrapped as long as their marginal costs are less than the full average costs of new plants (which we define as including switching costs). Industry-wide productivity (defined as labor hours per unit output) is, under the postulated conditions, the average labor productivity of all plants. It follows that the higher the percentage of new plants, the higher will be industry productivity. Productivity, therefore, depends on the rate at which modern plants are built. Such plants will be built for two reasons: a) to replace outmoded plants, and b) to satisfy demand increases stimulated by price declines (expansion). We will first consider the replacement decision.

As already stated, outmoded plants would be scrapped only if their marginal costs are greater than the full average costs. Since we have assumed that innovations are only labor-saving, gains from new plants will come from the reduction in labor costs, which is given by $W_t(L_{t-n} - L_t)$, where W_t is the wage rate at time t. Let $K_t C_t$ be the capital cost of the new equipment per unit of output (average costs), where K_t represents the units of capital required to produce one unit of output at time t and C_t is the cost of capital at time t. (Note that C_t is not the traditional return on capital. It represents the total cost of capital incorporated in the product,

properly calculated as shown in equation (1) under Overview.) Then, the plants built in period t-n will be scrapped if

$$W_t(L_{t-n} - L_t) > K_t C_t \qquad (1)$$

i.e., if the labor savings from a prospective innovation are greater than the total costs of adopting it. Multiplying through and rearranging terms, we then get

$$W_t L_{t-n} > W_t L_t + K_t C_t \qquad (2)$$

The left hand side represents the marginal costs of the old plants built at time t-n and the right hand side is the full average costs of the new plant.

Given the age distribution of plants within the firm, i.e. (the distribution of L_{t-1}, L_{t-2}, ... L_{t-n+1}, L_{t-n}), the probability that outmoded plants will be replaced by modern plants is the probability that

$$W_t (L_{t-n} - L_t) > K_t C_t, \text{ that is,}$$

$$\text{Pr} [W_t (L_{t-n} - L_t) > K_t C_t] \qquad (3)$$

Therefore, given an age distribution of existing plants, current labor, and capital costs and requirements, one can derive the replacement rate.

The second reason new plants will be built is to satisfy new demand. As labor-saving technology is introduced, labor costs will fall. As this happens prices will decline and demand will tend to increase. If we know or can determine the price elasticity of demand, then the increase in demand from period t-1 to period t can be derived, which is extremely important to our analysis, since this increase must be satisfied by establishing modern plants (assuming full capacity exists).

Therefore, under all the above assumptions, we can derived the two main economic factors determining investment in new technology: a) the rate that outmoded plants are replaced by modern plants, and b) the rate that modern plants are built to satisfy new demand.

This now allows us to see factors affecting these rates, which we call capital fixities. Capital fixities reduce marginal costs and thus reduce the amount of the left hand side of the formulation. The lower the marginal costs and the higher the switching costs then the higher all these critical costs fixities are and therefore, the lower the probability that firms will replace their outmoded plants. Consequently, productivity growth will be lower.

This model may be easily extended to encompass material and other cost savings (such as energy) as well as capital-saving innovations. The formulation will then appear as follows:

$$Pr \; [W_t(L_{t-n} - L_t) + M_t \, (Q_{t-n} - Q_t)$$
$$+ \; O_{t-n} > K_t C_t] \qquad\qquad (4)$$

where:

M_t is the material price at time t,

Q_{t-n}, Q_t are the quantities of material required to produce one unit of output at time t - n and t respectively, and

O_{t-n} is the _opportunity_ cost per unit of output of the old facilities. (In cases of major innovation the obsolescence may be such as to drive O_{t-n} to zero).

All of the above assumes no change in the product itself. However, the above can be further expanded to include product innovation as well. In this case, the probability that a plant built in t-n will be replaced by a plant producing a new product is given by:

$$\Pr\ [W_t(L_{t-n} - L_t) + M_t(Q_{t-n} - Q_t) + O_{t-n}$$
$$+\ (P_t^{**} - P_t^*) > K_t C_t] \tag{5}$$

where

P_t^{**} is the price of the new product at time t, and

P_t^* is the price of the old product at time t.

B.   Labor Fixities

If only capital fixities existed, the world would be a lot simpler, but in fact, other fixities exist as well which inhibit innovation. We begin here to examine less quantifiable factors as labor and management. We look first at labor.

Labor fixities refer to inertia on the part of blue collar workers (production workers) that impinge on managements' ability to adequately respond to change. This retraining may be due to organizational or power issues, often related to unions, or simply to the inability of workers to change or to adapt to an innovation.

Labor union power plays an interesting role in labor fixities, because it simulatneously increases the marginal cost of the existing labor force through higher wages, while increasing the average switching costs of either retraining through political opposition or new hiring, through the use of strikes. On the one hand then, unions help the adoption of innovation, while hindering it on the other. It is difficult to say which effect would likely predominate.

Also, the operational activities of a firm help to increase labor fixities. Firms seek to reduce costs through specialization of labor. This specialization coupled with volume production allows workers to move down the experience curve with the effect of reducing unit costs over time. Thus, the total marginal costs will decline, making the existing technology more and more attractive. However, the danger is that the more this occurs, the greater will be the switching cost involved in retraining workers for a new technology.

We should consider this problem as consisting of two stages. The first is focused on retraining. Specifically, we want to know what is the probability that a given worker will be able to successfully complete a retraining program. Then we need to know the probability of one who completes retraining of successfully re-entering the internal work force. We want to know what factors affect the success or failure of such stages. Different hypotheses can be generated; for example, we could hypothesize that labor fixity increases with time, in terms of time employed, time at a given task, and/or age of worker. We might also hypothesize that success is a factor of labor supply: the greater the supply the greater the motivation of the worker to succeed.

Also critical would be the educational base of worker vis-a-vis the new technology--the more unrelated or unique the latter is, the greater the difficulty in learning it.

We might also test the hypothesis that the degree of unionization will influence fixities. We have stated above some of the reasons for such a hypothesis.

C.   Managerial Fixities

Lastly, we suggest a third major factor that inhibits change--managerial fixities. This refers to inertia at the decision-making level of the firm that does not belong to capital or labor. It is the inability or unwillingness of management to innovate or adopt innovations when it is economically feasible to do so. In the long-run, it is this factor which is the determining factor, since most capital and labor fixities can be overcome in the long-run.

No doubt, this factor is multi-dimensional. It may partially be due to psychological resistance to change. People become comfortable with ways of doing thins and don't like the uncertainty generated by innovations. Thus, the longer a given strategy or policy is in effect, the more difficult it is to change it.

Another dimension of managerial fixity may be organization structure, i.e. the way the organization is structured may limit the degree of change or even the ability to recognize it.

It may also be that strategic moves themselves limit innovation. For example, Rumelt (1975) suggests that a strategy of vertical integration may be difficult to redirect, not only because of the capital fixities involved, but the scarcity of general managers under such a strategy.

At any rate it is clear that such factors do exist, and in our opinion contribute significantly to industrial demise.

D.   A Fuller Model

It is necessary then to add these two factors of labor and managerial fixities to our model. As you recall, or formulation was

$$Pr\ [W_t(L_{t-n} - L_t) + M_t(Q_{t-n} - Q_t) + O_{t-n}$$
$$+ (P_t^{**} - P_t^*) > K_t C_t]$$

This inequality determined if new technology would be adopted, i.e. it would be adopted if the savings were greater than costs. However, we now have seen that the savings must be greater than the capital costs plus labor and managerial fixities, i.e.

$$W_t(L_{t-n} - L_t) + M_t(Q_{t-n} - Q_t) + O_{t-n}$$
$$+ (P_t^{**} - P_t^{*}) > K_t C_t + \alpha + \beta$$

where α represents labor fixity and β managerial fixity. If then we find that we can identify the original terms, we can determine whether α and β were instrumental in a decision.

E.   An Empiricial Application

Let us examine how such a model can be applied to the automobile industry. We would like to look at the adoption of robotics by U.S. automobile manufacturers as compared to their Japanese counterparts. We do so by first determining if indeed Japanese technology is significantly different from that in the U.S., and whether it is predominantly labor-saving or capital-saving. Having established this, we then can use our model to analyze the non-decision of U.S. manufacturers to adopt robots in a full way prior to 1977.

If Japanese auto makers were to utilize the same technology as U.S. auto makers, they should hypothetically use more labor since their wage rates are much lower, and therefore their output-labor ratio should be higher than that in the U.S. However, using 1979 as an example, we observe in Table 2 that on the average, Nissan and Toyota produced 41.9 and 63.2 cars and trucks

Table 2

CARS AND TRUCKS PRODUCED PER EMPLOYEE PER YEAR

FOR NISSAN, TOYOTA & FORD

Year	Nissan	Toyota	Ford (U.S. operation only)
1980	45.7	69.0	11.9
1979	41.9	63.2	13.5
1978	42.3	63.4	15.9
1977	43.8	59.0	16.6
1976	42.8	55.4	14.5
1975	41.0	51.2*	13.1
1974	35.9	48.5	14.1
1973	37.8	55.5	15.1
1972	37.3	50.9	15.3
1971	33.3		13.8
1970	29.2		13.0
1969	24.8		
1968	22.6		

SOURCE: Annual Reports of Corporations Involved.

respectively per employee, while the same figure for Ford's U.S. operations[1] was 13.5.

This sizeable difference would seem to indicate that the Japanese have adopted a different technology than that used by Ford. However, one could argue that this the unit/employee ratio is affected by the amount of vertical integration, i.e. firms with less vertical integration would generally use less capital and labor to produce the same level of output than firms with more vertical integration, so that less vertically integrated firms would have a higher output-labor ratio and/or output-capital ratio. Nevertheless, vertical integration only partially explains the difference in the output-labor ratio between U.S. and Japanese auto makers. Let us see why.

According to the census of Japanese manufacturing for 1978, for example, an employee in the entire Japanese automobile industry produced, on average, 14.5 cars per worker. This means that if a Japanese auto manufacturer were 100% vertically integrated, its output-labor ratio would be 14.5.

In comparison, Ford's output-labor ratio in that year was 15.9, but its percentage of vertical integration was 29%. If we assume labor intensity is constant along the production line, then if Ford were 100% vertically integrated, each employee could produce 4.6 cars and trucks in that year ($15.9 \times (29/100) = 4.6$). This figure is obviously significantly lower than the 14.5 cars produced by Japanese workers.

Thus we may conclude that vertical integration cannot fully explain the observed difference in the output-labor ratio. The Japanese must then have adopted different technologies that allow Japanese auto workers to be more productive. Indeed, we can also see that their technology is labor-saving,

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[1] Similar data for G.M.'s U.S. operations are not available.

rather than capital-saving, by looking at the difference in the capital-output ratio. Taking Toyota as an example and using 1979 as a sample year, gross plant and equipment per unit of car and truck was $1655 (the exchange rate is 2/7 Yen = $1), which was significantly lower than that of both GM ($2,326) and Ford ($2,175). However, this ratio again is potentially misleading, being overstated due to Toyota's low degree of vertical integration. As with labor, other things being equal, the lower the degree of vertical integration, the lower the capital input and thus, the lower the capital-output ratio. Therefore, the capital-output ratio should be adjusted for the degree of vertical integration. In 1979, we have calculated that the degree of vertical integration was 35% for GM and 29% for Ford. Assuming that Toyota uses the same technology as the average firm in the Japanese auto industry, for Toyota, its vertical integration is estimated to be the industry output-labor ratio, over Toyota's output-labor ratio because for the industry the former means 100% vertical integration. This ratio turns out to be 23%. Again, if we assume capital intensity is constant along the production line, then, we can determine Toyota's requirement for capital per unit of output if it has vertically integrated to the same degree as GM and Ford.

If it were 29% integrated it would require $2,087 of capital per car (1,655 x 29/23) and $2,518 if 35% integrated (1655 x 35/23). If we compare these with the actual requirements of $2,175 for Ford, and $2,326 for GM, we find that the differences are not statistically significant. Thus we can conclude that the technology employed by Toyota requires almost the same amount of capital per unit of output as that employed in the U.S. In other words, Toyota's technology does not appear to be capital-saving.

Therefore we have thus far shown that, after correcting for differences in the degree of vertical integration, Japanese auto manufacturers are most likely to employ a different technology than that used in the U.S. and that this technology is more probably labor-saving and not capital saving. These calculations, of course, are crude, but should approximate reality, and they also show the conditions we observe are very similar to the assumptions of our theoretical model. To refresh our memory, formulation (1) is

$$W_t(L_{t-N} - L_t) > K_t \, C_t.$$

We will try to estimate $K_t C_t$ first and then we can see how this might have affected the decision of GM and Ford not to adopt robots.

Robots were employed by Japanese manufacturers in the early 1970's. However, it was not until 1977 that U.S. auto makers started modernizing their plant and equipment to any significant degree. This may be observed from the time series of capital expenditures for GM and Ford which are shown in Figure 1(a,b). From the figures we may observe that GM and Ford's capital expenditures have been increasing substantially since 1977. Of course we do not know what percentage of this was merely for replacement of worn out equipment and not for new technology, but it seems safe to assume that the decline prior to 1977 surely indicates no significant adoption of new technology on any large scale before that time. So the question is: why so late? To answer this, we must go back to early 1970's to study why U.S. makers did not wholeheartedly embrace robots at that time.

To examine the question, we need to calculate values for K_t, C_t, W_t, and L_t and plug them into our formulation. Since it appears that the robotic technology is not a capital-saving one, we assume the capital units required per output in 1970 should approximately be the same as in 1978. In
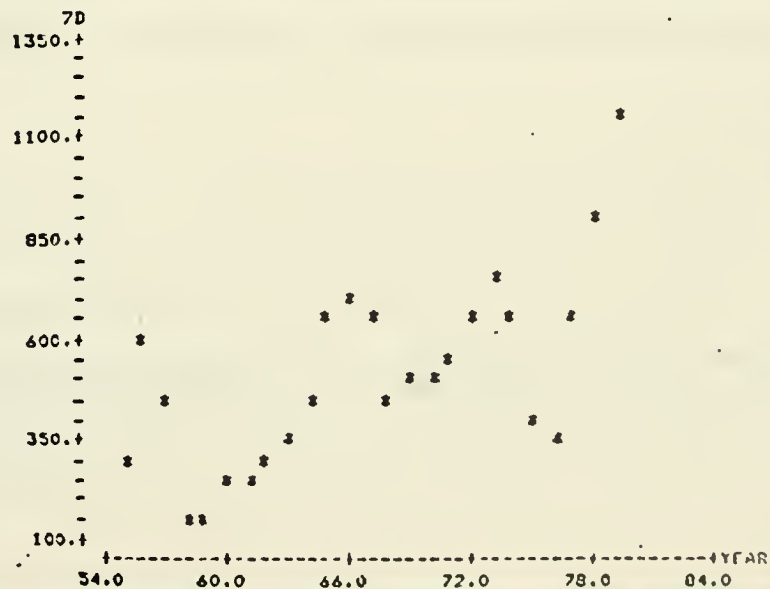
FIGURE 1

CAPITAL EXPENDITURES

FOR GM AND FORD (IN CONSTANT DOLLARS)

1955-1979

(a) General Motors
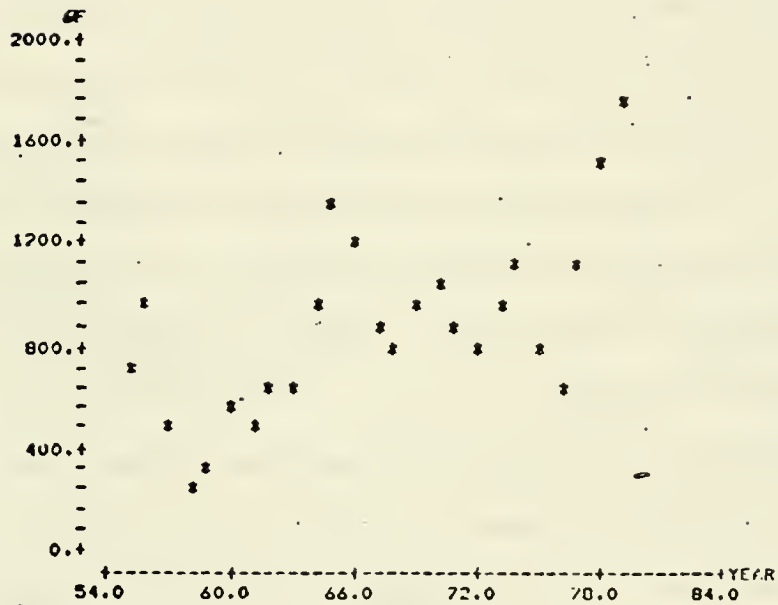
(b) Ford

plot c173 c102

our previous calculation, we determined Ford would require $2,087 for plant and equipment in 1979 to produce one automobile, if it were to use the same technology employed by Toyota. If we deflate this figure by the producer price index back to 1970, it becomes $1,289, which is the value for K_t in our model. As for the cost of capital input, C_t, this will depend on the time frame used by decision-makers in estimating the life (# of units it will produce) of the investment, as well as the cost of borrowing. If management uses a five-year frame then we must divide the $1,289 figure by 5 indicating an amount of $257.80 per vehicle per year. We then multiply this by the cost of borrowing. In 1970, Ford issued a $125 million note carrying an 8.25% interest rate. If we add 1 point for transaction costs, we can estimate the cost of raising additional capital to modernize its plant and equipment at that time to be 9.25%. Therefore by multiplying the $257.80 by 1.0925, $K_t C_t$ becomes $281.64 per unit.

We should point out the critical importance of the time frame utilized by management in making investment decisions. For example, if a 3 year framework is used, the figures comparable to the $257.80 figure would be $430. For a 7 year perspective, it would be $184. The time frame will probably vary across industries and should be a function of the technology, competitive dynamics and managerial attitudes. We have no data on what is used in the U.S. automobile industry, but we assume a five-year frame to be reasonable.

Now we must calculate W_t and $(L_{t-n} - L_t)$. In 1970, the wage rate was $6.40 per hour. Therefore without labor and management fixities, according to formulation (1), Ford should use robots if robots could save 44 labor-hours per unit of car $[(L_{t-n} - L_t) > K_t C_t / W_t = \$281.64/6.4 = 44]$.

Unfortunately, we do not have data regarding the saving of labor-hours by robots in 1970, but we may estimate this number using Abernathy's study and our own calculations.

Abernathy's study shows that Japanese factories in 1980 could build a compact car with 65 fewer labor-hours than U.S. factories. We also estimate that in 1979, it took 108.4 labor-hours for Ford's U.S. employees to build a car or truck.[2] For Toyota, we conservatively estimate this to be 34.8 hours. We derive this estimate by assuming Japanese workers work 44 hours per week and 50 weeks per year, then multiplying this number by the total number of workers, to derive total labor-hours, and dividing total labor-hours by units of output, to get labor-hours needed to produce a car. However, this number should be adjusted for vertical integration as before. The resulting numerical value is 43.9 hours for Toyota. Thus, the difference between Ford and Toyota in labor hours required to build a car is 64.5 hours (108.4 - 43.9), which is very close to what Abernathy estimated in his study, referred to previously. We will use this number as a base to estimate the savings in labor-hours in 1970.

If the functional properties of robots have improved 5% per year since 1970, then robots would have saved 40 labor-hours per car in 1970 [$40 = 65/(1.05)^{10}$], which is slightly lower than the savings of 44 labor-hours our calculations indicate that Ford needed to make a decision to replace old equipment.[3]

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[2] labor hours = total payroll/hourly wage rate.

[3] This is again a conservative estimation. From Table 2, we can calculate that Toyota's labor physical productivity (defined as output per employee) increased 3.87% per year from 1972 to 1980, and Nissan's increased 3.10% per year from 1970 to 1980. Thus, 5% increase in functional property underestimates the saving in labor-hours that could have been realized in 1970.

This indicates that, at least according to our crude calculations, management was justified in not fully adopting robots in 1970, based on purely economic data for capital. If anything these are overstated because the cost of capital is more than just the cost of borrowing (9.25%). But in addition to capital fixities, there are others as well that may have played a role in the non-adoption decision, particularly, what we have termed, labor and managerial fixities. To better understand how these and other factors may impact such decisions, we now turn to examine empirical research on the adoption of innovation.

V.   ADOPTATION OF INNOVATION

Somehow these fixities must be overcome in order for proper resource allocation to occur. However, we need to be able to adequately identify the dimensions and to quantify possible surrogates. In order to better get a grasp of this, we would like to examine research that has been done focusing on the adoption of innovation.

This is useful because it is difficult to empirically examine the events leading up to the invention or innovation of a particular product or activity, as this is often a long, cumulative and non-separable process (See Parker, 1974). However, once an innovative process or product comes into existence, it is much easier to empirically measure its adoption by firms over time.

Rogers (1971) has chronicled at least six disciplines that have contributed to research in this field: anthropology, sociology, education, medical sociology, communication and marketing. These have examined how such things as new ideas, products, social programs, and technologies have been accepted or adopted over time. The unit of analysis has almost exclusively been individuals and the research has generally relied on surveys and statistical analysis. One of the major findings has been that the pattern of the rate of adoption generally conforms to S-shaped logistic curves. Adopters have often been divided into various categories which are then further investigated to identify the behavioral, psychological and sociological characteristics of each category. Five such categories coined by Rogers (1962) are: innovators, early adopters, early majority, late majority and laggards. Researchers have concluded, for example, that early adopters have higher social status, more years of education, more favorable attitude toward risk, less dogmatism, greater intelligence and more social participation.

While this research has made considerable progress in furthering our understanding of potential factors inhibiting innovation at a personal level, it is questionable how much of it can be transferred to the business enterprise. For the latter, one must delve, in addition, into issues of centralization and decentralization and the governance structure of the firm. And this because within the firm the effect of individuals on the decisions of the organization and of the organization on the behavior of the individual should be a function of the model under which the firm is operating. Using Allison's three models of decision-making (1971), we would hypothesize that a firm operating under the so-called "rational" model (Model 1) would be less likely to be affected by an individual's attitude toward innovation than it would be under the behavioral model (Model 2) and even less so then a firm operating in a bureaucratic mode (Model 3). A possible exception may be found in the case of the "top" decision-maker in Model 1, but even here, if the innovative behavior is part of the norm for the industry, it would be imposed on the organization by the markets and not by any one individual. If, however, the Model 1 top decision-maker deviates from the industry norm, i.e., he/she assumes the role of the innovative entrepreneur, then the strategy chosen by the top would influence the structure of the organization and hence the behavior of the individuals below the top. This of course is not necessarily applicable for behavior under Models 2 and 3. The aforementioned have interesting implications. If the assumptions associated with the various models hold, it means that top management could actively align personnel and unit structure to encourage innovation in specific units and thus overcome labor and management fixities.

Economists, who have been largely ignored in Roger's summary, have mainly relied on the "rational" model of the firm (Model 1) in examining

diffusion of technological innovations within firms and industries. Mansfield (1961), in his seminal work, for example, hypothesized a relationship where the number of non-adopters of innovation at any point in time is a function of:

1) the profitability of installing the innovation relative to alternative investment (negative influence),

2) size of investment/total assets (positive), and

3) proportion of firms already having adopted (negative).

The first variable attempts to measure the return accruing from the investment as an incentive, and the last accounts for the associated risk, while the second factor deals with the size of the commitment relative to that of the total firm (which also is a component of risk). However, determining the profitability of an investment may not be such an easy task, and it must be evaluated in terms of the firm's existing technological state as well as that of ancillary industries. Furthermore, Mansfield's measure is ex post, but it is anticipated (ex ante) profitability that is the determining factor in the investment decision, and these often do not coincide. Finally, this variable (profitability) is measured by the average payout period required to justify investments divided by the average payout period actually achieved for the particular innovation. This is an extremely crude measure and, in our opinion, does not capture the economic decision confronting the firm. We should compare the marginal cost of the old and the average cost of the new, as we have explained previously.

Mansfield's empirical results confirmed these hypotheses, but they are all measured at the industry level, in the aggregate, and do not deal with decisions at the firm level. Furthermore, the so called epidemic or contagion models are based on the following two assumptions that are potentially

unrealistic when applied to innovations: 1) the spread of innovation, as in the case of infectiousness of the disease, must remain constant over time for all individuals, and 2) all individuals must have an equal chance of being affected (See Davis, 1979). However, as Gold has persuasively argued (1981), neither of these two assumptions often hold true because: 1) the nature (and therefore the benefits) of an innovation change over time; 2) the benefits vary across firms; and 3) there are varying degrees of commitment to the innovation. Therefore he concludes that one needs to examine the decision-making context of the innovation, ex ante, to understand the diffusion process. In sum, Gold states:

> There is obviously little basis for assuming that all firms in the seemingly relevant industrial grouping are even giving serious consideration to the same innovation within a given year[1].

And further:

> It seems necessary that research focus more directly on the processes of relevant decision-making as it is taking place, or immediately after its conclusion... and that such explorations also seek to analyze the actual quantitative estimates presented for managerial consideration...[2]

He argues then for more of a focus on process research rather than merely looking at the variance at any one point in time (See Mohr, 1978). However, while Mansfield's work does have shortcomings, it was an important step in empirically examining adoption factors parcticularly focusing on what we call critical fixities. His variables indicate as we have proposed, that fixities must be considered at any one point in time as well as over time. For

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[1]Gold (1981) p. 255.

[2]Ibid, p. 261.

example, the size of the investment must be evaluated in relation to the size of the firm, at a point in time. At the same time fixities will change over time, often in different directions. For example, as others adopt an innovation managerial fixities may be reduced, while capital fixities may increase.

Rosegger (1979) made some further headway in researching the process of innovation adoption at a less aggregate level by examining the introduction of continuous casting among steel producers. He found that indeed the steel producers were not one homogeneous set of potential adopters but rather he identified three groups, differing in their particular "technological specificity", including such things as scale of operation, degree of vertical integration, and production programs.

This work is significant in light of previous research for several reasons:

i) it questions the structuring of Mansfield's model which views innovations as equally profitable across the industry and over time;

ii) it shows that firm and industry characteristics may change the attractiveness of the innovation;

iii) it strongly emphasizes the importance of the firm's technological state and type of development in affecting its decision to adopt.

These combine to illustrate some of the issues associated with capital fixities and how they may differ across industries and across firms. However, he does not examine labor fixities or managerial fixities. Yet Rosegger's work points clearly to the need to study carefully industry and individual firm characteristics in identifying critical factors related to innovation adoption, especially the technological characteristics of a firm's strategy.

Rosegger's work demonstrates the necessity of evaluating an innovation in the context of the state of a unit's technology - its technological specificity. Perhaps the historical tradition of innovation research has portrayed innovation as inherently beneficial but in fact it is not necessarily so. The later adopters may not in fact be "laggards", "drones", and "diehards", as they have been labeled in the literature, but may, in fact, be making decisions that are economically and strategically rational.

In the case of billet casting, Rosegger found the larger integrated producers adopted the innovation only incrementally (which was relatively less economical to the firm than complete replacement) due to the need of greater flexibility because of their variegated mix of products and also because of their strategic decision to handle higher grade products.

Within slab casting Rosegger also found a difference between segments, for reasons similar to those stated above with the added factors of market conditions and the continuing need for learning. With this innovation, he contends, a wait-and-see attitude paid off.

Rosegger's conclusions point to the existence of strategic groups (See Newman, 1972) within an industry, albeit along mostly technological lines, and the differential effect of different strategies on innovation and vice-versa. For our purposes, his work demonstrates the existence of fixities at both the firm and industry level, i.e. some are endemic to the industry and others to the individual firm. His work also indicates that a closer examination of the nature of the capital technology is necessary, for what may appear to be labor or managerial fixities are actually capital fixities embedded in the technology. Also, his data indicate, although he does not emphasize this, the importance of strategies upon the innovation decision, which perspective we have strongly recommended.

Mansfield also examined differences among individual firms in terms of the speed with which they adopt a particular innovation. He proposed the following relationship (1963):

$$\log d_{ij} = \log Q_i + a_{i2}\log H_i + a_{i3} \log S_{ij} + a_{i4} \log G_{ij} + a_{i5} \log A_{ij}$$
$$+ a_{i6} \log P_{ij} + a_{i7} \log L_{ij} + a_{i8} \log T_{ij} + \log \epsilon_{ij}$$

where d_{ij} is the number of years the firm waits to adopt

S_{ij} is the firm's size

H_{ij} is a measure of the profitability of the investment

G_{ij} is the firm's growth rate

P_{ij} is the firm's profitability of the investment

A_{ij} is the age of its president

L_{ij} is the measure of its liquidity, and

T_{ij} is the firm's profit trend.

In this equation Mansfield attempts to capture both economic and behavioral characteristics. He hypothesized that the larger a firm, the more likely it is to adopt early, since i) it is better able to bear risk; ii) it has a greater probability of needing new equipment for replacement, and; iii) it has greater new application possibilities due to alleged greater variety of operations. Also, he expected that the firm's rate of growth would positively affect adoption because this would call for more expansion, and that its profitability and liquidity would provide resources for more adoption. The variables of age of president and profit trend were introduced in an attempt to add behavioral factors, the hypotheses being that: the older the president

the less likely to adopt early, and declining profit would activate search--
and thus new directions. Mansfield used data from 167 firms adopting 14
different innovations in U.S. industries. He only found H_{ij} (profitability
of the innovation) and S_{ij} (firm size) to be significant, but the latter for
only 2 of the 14 innovations.

Nabseth (in Williams, 1973) examined data from Swedish firms, using nine
explanatory variables, including some of Mansfield's variables as well as
others. He also found only size and profitability to be significant, and
found some indication that firms are more likely to adopt the sooner they know
of the innovation and the more receptive to innovation they have been in the
past.

However, in light of some of the criticisms presented earlier and the
instability of findings to date, we could conclude that regression analyses
are very limited in their utility-- at least they have been to date. Rather,
we see the research moving toward more of a focus on decisions at the firm
level within specific industries along the lines we have been arguing.

This brings us to another piece of research which looks at innovations
in the automobile industry in particular.

William Abernathy's book, The Productivity Dilemma is an excellent
descriptive analysis of the evolution of the U.S. automobile industry,
particularly in terms of technological development linked with strategic
management. It is important in our analysis because:

1)   it is an example of the level of analysis that we are supporting;

2)   it is one of the most recent works on the U.S. automobile industry,
     and it will be helpful to show how our approach differs from it; and

3)   it is rich in historical data that will help support our
     theoretical propositions.

The author attempts to discern patterns across different "productive units" such as the automotive assembly plant and engine plant, and he finds the following:

> As the product and the manufacturing process develop over time, costs decrease, product designs become more standardized, and change becomes less fluid. At the same time, production processes, designed increasingly for efficiency, offer higher levels of productivity, but they also become mechanistic, rigid, less reliant on skilled workers, and more dependent on elaborate and specialized equipment. Perhaps of greater importance, the nature and sources of technological innovation shift with these structural changes in product and process. Innovation becomes more incremental. Major innovations, with potential to reshape the product or greatly improve productivity, originate more frequently outside the firm and the industry. Development in productivity continues until the industry reaches stagnation. Stated generally, to achieve gains in productivity, there must be attendant losses in innovative capability; or, conversely, the conditions needed for rapid innovative change are much different from those that support high levels of production efficiency.[3]

As one can see the 'dilemma' he sees is the conflict between productivity (efficiency) and innovation. In our analysis, we have defined productivity in terms of value-added, thus including results from innovative activities within the productivity measure. Nevertheless, Abernathy is addressing the same issue we are probing -- that of critical fixities as inhibitors of innovation although he does not use our terminology. His work is useful particularly in his presentation of historical data, but his model which he develops is mostly descriptive, while we are more interested in determining underlying causes, in explaining why or how certain factors act as inhibitors, not merely in their identification.

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[3] Abernathy (1980).

For example, two conclusions drawn by the author are:

1)   an increased reliance on outside sources to originate process
     equipment innovations is expected as a productive unit advances in
     development.

2)   in terms of innovative activity each major company has more
     frequently made contributions in a particular area (Ford: process
     technology; GM: major performance components).

However, the reasons why these described phenomena occurred is not provided --
and they are extremely interesting questions, at least to us.

The model Abernathy develops is seen in Figure 1. At the top of that
Figure we can see the pattern he observes, mainly, in each productive unit, we
can observe in its beginnings, a very fluid environment with rapid product
innovation up to some point where a "dominant design" is reached, at which
time the rate of product innovation begins to rapidly decline while that of
process innovations increases, which then also reaches some peak point and
begins to decrease. Gradually movement is toward a "specific" state which is
much more stable and where change more incremental.

The Figure also provides some of the main characteristics of the Fluid
and Specific state. Abernathy sees several aspects of regularity in the
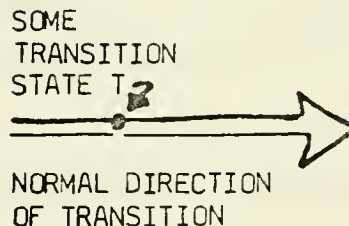
Innovation and Stage of Development
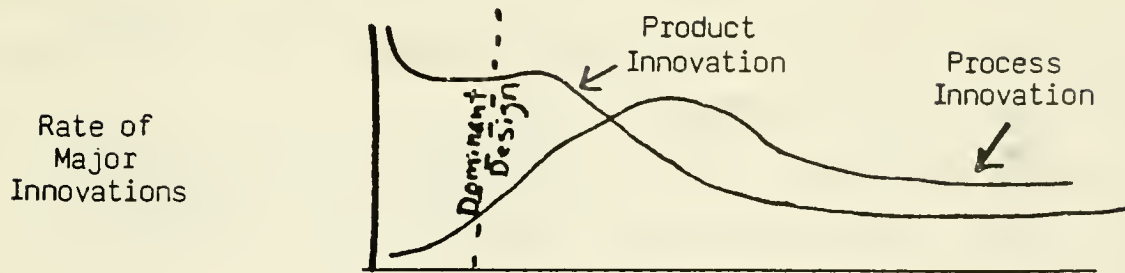
FLUID   Normal direction of development⟶ SPECIFIC
transition

FLUID
INITIAL CONDITIONS
(PATTERN 2)
-INNOVATION
● Emphasis on maximizing product performance
● Stimulated by information on user needs
● Novelty or radicalness high
● Frequency rapid
● Predominant type is product V.I.S. process

- PROCESS SEGMENT
STATE
o Production process & organization is flexible & inefficient
o Size or scale is small
o General purpose equipment used
o Available materials used as inputs
o Product is frequently changed or custom changed

TRANSITION AND BOUNDARY
CONDITIONS

F BOUNDARY   S BOUNDARY
CONDITIONS   CONDITIONS

SOME
TRANSITION
STATE T₂

NORMAL DIRECTION
OF TRANSITION

SPECIFIC
TERMINAL CONDITIONS
(PATTERN 1)
-INNOVATION
● Emphasizes cost reduction
● Predominant mode is incremental for product & process
● Effect is cummulative
● Novel or radical innovations occur infrequently & originate outside process segment
● Stimulation arises from disruptive external forces

- PROCESS SEGMENT
STATE
● Production process is efficient, systemlike, capital-intensive
● Cost of change is high
● Scale & facility market share is large
● Special purpose process equipment used
● Specialized input material used or vertical integration is extensive
● Products are commodity -like & largely undifferentiated

Figure 1

Source: William Abernathy, 1978.

Transition phase, including:

i)   a dominant design from which point the rate of product
     innovations decreases.

ii) decrease in product line diversity decreases over time.

iii) changes in the types of innovation change to ones that are
     more incremental and cumulative in effect.

iv) declining costs through learning curve effects.

v)   less reliance on skilled labor.

vi) changes in product design criteria, from uncertain to more
     well-defined.

vii) R&D that is less user-driven and more determined by formal
     internal policy.

The author then uses data from two such productive units at Ford to support
his model. However, one is still left with several nagging questions,
revolving around the question of causality.

For instance, it is not clear what makes a dominant design. Abernathy
sees the evolution toward this standardized design "almost as if there were a
natural logic to standardization," and once there, the pattern of
process/product innovation changes.[4] The author seems to believe this may
be a natural technological state and also partly consumer determined. In
fact, it may have nothing to do with either but rather may just be the point
at which product innovations are exhausted -- not technologically, but by
labor and management, because they have become fixed in their conception of
what a "car" looks like. Thus it could be a managerial fixity. The situation
may be similar to that which generated the birth of the auto industry.

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[4]Abernathy, p. 21.

Abernathy notes how it was new firms that were prime movers in emerging automobile manufacturing because the established transportation equipment manufacturers thought in terms of commercial and industrial transportation, rather than a lightweight vehicle suited to personal transportation.

Furthermore, it is not clear whether Abernathy's model merely explains what must occur (and therefore one needs to know merely how to manage the process), or whether human intervention can change the model itself.

In our opinion the matter of changes is a major weakness of the model. Abernathy points to reversals that appear to be occurring, but he is not very specific in describing what causes such changes and how the model explains it. He does say that changes are due to exogenous factors and that the changes will occur in a backward order -- starting incrementally and eventually changing the dominant design, but very little space in the book is devoted to this. In our estimation it is the response to change that is most critical -- how one breaks existing patterns to improve performance, i.e. overcome critical fixities.

It is our opinion that while Abernathy has provided a foundation, we must move to a higher level of abstraction to understand what we observe over time. This level we have delineated in the previous section. We believe what we have proposed is supported by the data that Abernathy has provided, and provides a richer approach to identifying and measuring the impact of various causes and inhibitors of innovation of both types, process as well as product.

VI.   CONCLUSION

In summation we have addressed the problem of innovation as the primary means of improving productivity in the long-run. Thus, one of the problems facing the firm is the determination of technological change so as to measure potential rewards. To this end we discussed various approaches that have been taken and the advantages and disadvantages of their usage.

We then presented an investment model that should characterize the types of variables considered in the decisions of managers and then moved to the more specific decision to adopt new innovative equipment. We develop the notion of critical fixities as major determinants of the innovation decision, in three areas - capital, labor and management. The model we develop incorporates these variables - albeit somewhat crudely - as a means of geginning to identify and assess their impact. We have applied these very roughly to the automobile industry in order to show how these variables can be approached. However, much empirical work remains to be done in order to confirm our model and the affects of these fixities. We have presented a reveiw of empirical work that has been done in the adoption of innovation literature both as a means of showing some confirmation of our hypotheses, but even more to show how much more must be done.

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